WBANs for live sport monitoring : an experimental approach, early results and perspectives

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WBANs for live sport monitoring: An experimental approach, early results and perspectives

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Abstract— **In this paper we present a simple Body Area Network (BAN) platform that was built to monitor the performance of a marathon athlete all along the race, meeting real-time and QoS constraints, under good transmission conditions. Data collected during the event (packet loss, signal strength) allowed us to obtain a primary knowledge about the behavior of the radio transmissions between the different links in the network. The results of this experiment and the important disparities observed between the links point out the need to improve the transmission strategy.**

***Keywords*—Body area networks, wireless sensor networks, cooperative communications, sport monitoring, real time communications**

I. INTRODUCTION

A new interest in sports is to get inside the event through the collection and live exploitation (e.g. broadcast) of various data (e.g. physiological, motion, geographical...) concerning the sportsmen's behaviour during the event. This can be achieved with the help of wireless sensors located at some points of interest on the body, and transmitting the measured data to a collecting sink where it can be interpreted. It is quite obvious that this specific field of application of the general Wireless Body Area Networks (WBANs) communication systems has to face its own constraints, which are very different and scenario-dependent from the usual medical healthcare monitoring.

While several experiments have been derived in simpler conditions [1-3], such as in anechoic chamber, hospital room or isolated walker or runner, there is still a lack of experimental results in more realistic scenarios.

The experiment we present in this paper was designed for the Marathon of Paris, which took place on April 15th, 2012, in collaboration with the companies Euromedia and France Television. Our challenge was to design a platform that could collect in real time the data collected on a runner's body, which was then inlayed with the video flow and broadcast on TV. The result consisted in several live TV sequences of the athlete's performance during the race (Fig. 1). For this experiment we had to focus on the data collection in a highly dynamic and dense outdoor environment (40,000 participants), while fulfilling the streaming constraints.

The detailed experimental scenario, conditions and constraints, and the whole platform design are explained in section II. As we collected data about the transmission links, we were able to analyse different aspects of the radio communication, which are presented in section III. This prior knowledge can be considered as a starting point for defining more efficient strategies for the data collection, which would allow the extension of the network to a group of athletes, as discussed in section IV. We draw here some challenging issues.

Fig. 1. Example of a TV screen capture, showing in parallel the video flow and the live data display (stride frequency, number of steps) during the Marathon of Paris 2012.

II. A SINGLE BAN EXPERIMENTAL CASE

This section presents in detail the design of the operational platform we built according to a specific scenario, consisting in a wireless real-time data collection and exploitation of a Marathon athlete's performance, in a dense and highly dynamic environment.

A. Context of the experiment

The ideal application scenario for an event such as a Marathon would be to equip all the athletes with a set of sensors, and collect all their data in real time. This is a complex problem that needs preliminary experimental and theoretical steps. As a first experiment, we proposed to validate a simplified scenario, with only one athlete equipped with 3 sensors (motion sensors with a GPS on the pelvis, motion and insole pressure sensors on each ankle), as shown in Fig. 2.a**.** The data transmitted by the sensor nodes were collected by a router located on a motorbike few meters ahead of the runner during the whole race. The router acted as a gateway in charge of transmitting the collected data to the broadcast network as a side information channel of the video stream from the mobile camera.

The design of the system was done in order to fit the transmission conditions and constraints explained hereafter for an operational application. We also had the opportunity to collect a real condition database concerning the link quality for the whole event, allowing a primary analysis on the behaviour of such a network. This scenario involves an important body motion and human density, which are known to have a strong impact on the quality of the transmission [1]. They are indeed important causes of shadowing and therefore packet loss in the 2.4 GHz ISM band we used.

B. The equipment

All the equipments for the platform were provided by the company HiKoB. HiKoB Fox sensors were located on the athlete's body, communicating with a HiKoB Lion router. We also used insoles equipped with Force Sensitive Resistors (FSR), physically connected to the Fox located on the ankles. They acted as switches to let us know whether the foot was in contact with the ground or not.

Fox sensors embed an Inertial Measurement Unit (IMU) for motion analysis; they can also integrate a GPS daughterboard for speed and location measurement. They integrate chip antennas on the PCB, with an omnidirectional radiation pattern with 0dBi gain. The router was equipped with an external omnidirectional 9dBi gain antenna on the top of a pole at the back of a motorbike for more visibility.

Both systems use the same radio chip, which is an Atmel AT86RF231[14], IEEE 802.15.4 compliant, for the 2.4GHz ISM band, divided into 16 narrowband channels, with a 250kbps transmission rate. It integrates a Cyclic Redundancy Check (CRC) for error detection, and gives access to an Energy Detection measurement (ED), which is an average of the instantaneous Received Signal Strength Indication (RSSI) over the last 4 bytes received.

The company Euromedia was in charge of integrating the output of the router into a longer range data collection link using high speed wireless links toward a repeater on a helicopter and back to a mobile video truck, and of the live data broadcast. Data streams were stored in a database located in the video truck and visual integration of sensor data on the broadcast signal was made using overlays.

C. Measurements performed

Using the motion sensors (accelerometers) on the ankles, the insoles and the GPS on the pelvis, we were able to extract and transmit the following measurements:

- Shocks
- Stride frequency
- Number of steps
- Speed
- Localization
- Tiredness index
- Time of flight (both feet in the air)

D. Transmission conditions

Although the density of the running athletes was important and evolving, we managed for this experiment to keep rather good conditions for the data transmission all along the race, which means the collection point located on the motorbike wasn't more than 10 meters far beyond the athlete, rather stable, keeping as much as possible permanent Line of Sight (LOS) transmissions for each node, if we except other bodies.

Transmission power was not constrained for this first experiment, since the battery was estimated over sized for the race duration and no interference have to be accounted for. Thus, any data transfer was done at 0dBm.

E. Constraints

Since the collected data was exploited in a live streaming flow, the most important constraint was the latency of our system, so that any valid data packet would arrive within 90ms in order to avoid synchronization problems between the data and the video flow. This strong constraint led us to adopt the following network design and protocol.

The 3 aspects of the dynamicity of the global system, i.e. the athlete's motion, the density evolution and the router movements, were also important constraints, which were hard to evaluate beforehand. Despite this uncertainty, the design of the system had to guarantee a good Quality of Service (QoS), which means in our case ensuring a continuous data streaming.

F. Design of the system

The network topology we adopted is a standard star topology (Fig. 2.a), each node communicating independently with the router. We made this choice because of the presupposed Line of Sight condition on the links.

Concerning the transfer protocol, we had to design it in order to meet the latency < 90ms constraint. Among the existing MAC protocols available for our chipset, Time Division Multiple Access (TDMA) offers the advantage of avoiding interference between the nodes, and to keep a constant latency, which is better suited for our real-time application [15-16].

We adopted this simple protocol (Fig. 2.b), consisting of three steps:

- All nodes wake up at the same time, before the synchronization beacon,
- A synchronization periodical beacon of period T = 40ms is broadcast by the router,
- Each node transmits its data to the router within predetermined time slots, then turns its radio chip to sleep mode.

We also added an active search method to this protocol: in case the synchronization was lost (more than 3 consecutive beacons missed), the node would be permanently listening until the reception of a new beacon, ensuring a quick resynchronization within 40ms.

In addition to this, to be more resistant to narrowband interference and use the whole spectrum, we implemented a

Frequency Hopping method, each packet being transmitted on a different channel, according to a predetermined sequence.

Furthermore, to achieve the QoS constraint and limit the impact of the shadowing due to the body motion, we implemented a simple repetitive channel coding, consisting in sending 3 times each data packet using frequency hopping, to ensure a higher transmission success probability. In practice, each packet at time slot t_n gather the data from this period and the two previous period t_{n-1} and t_{n-2}.With this method, we obtained most of the time 40ms or 80ms latency and in worst cases 120ms, but as the results illustrate in section III, this worst case had a probability of few percents. According to the original packet size and the simple addition of redundancy we implemented, the radio nodes, thus the transmission channel, were active for a duration of 12ms, the remaining time of each TDMA period being used for the sensors' data acquisition and preparation.

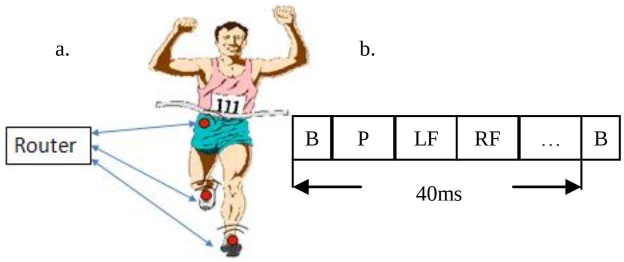

Fig. 2. a: Star network configuration. b: Periodical TDMA protocol (4 emission slots, B: Beacon, P: Pelvis, LF: Left Foot, RF: Right Foot, remaining time used for the data acquisition).

III. Experimental Results

From this experiment we were able to extract different features about the 3 links of our BAN (from the sensors to the router), from the general evolution of the whole network along the race, to the individuality of each link.

A. Data collected

The data of interest we could store all along the race were the following:

- Success/failure of each transmission at a packet level (i.e. packet loss).
- Energy Detection measurement, which is an average of the instantaneous RSSI over the last 4 bytes received per packet.

Concerning the packet loss, in the following results we focused on the transmissions from the sensors to the sink. A packet was considered lost when it didn't reach the sink at all or was not properly decoded (wrong CRC). The packet loss information is given here for one hour of transmission, representing 90000 samples.

B. An evolving environment

Fig. 3 represents the Packet Error Rate (PER) evolution on each link, computed for each sample as a moving average on the instantaneous packet loss over 1000 samples (40 seconds). From these curves we can identify three different phases:

1) Beginning of the race:

During this short period of time we observe an important PER due to the important number of runners starting the race at the same time (several thousands). This is a transition phase for which the network efficiency is critical, mostly due to the fact that the router couldn't get close enough to the athlete and NLOS propagation conditions occur.

2) First half:

For this period the athlete is still in a dense configuration, surrounded by many others who may behave as obstacles for the transmission links between him and the motorbike. This explains why the PER remains globally high. Important variations occur during this phase, because of these transitions from Line of Sight (LOS) to Non Line of Sight (NLOS) due to the other athletes, and also to the movement of the motorbike (getting farther or closer, adapting to the group of runners...).

3) Second half:

In that second half-hour we observe general better transmission conditions, a PER globally lower and less variations, in brief the network is much more stable. This is because during a Marathon, the group of runners, very dense at the beginning, tends to spread after a while, each athlete running at his own speed. As a lower density also involves a closer router, we approach the LOS condition.

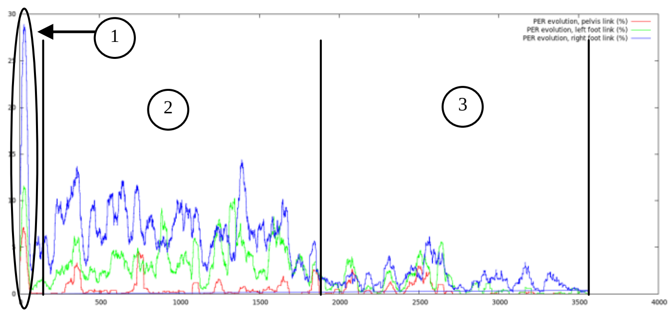

Fig. 3. PER evolution (%) vs time (s) over the first hour for each link (Red: pelvis, Green: left foot, Blue: right foot); 3 phases: 1. Beginning of the race, difficult contact; 2. High density evolution; 3. Lower density, quasi-LOS transmission.

C. Important disparities between the links

The following curves (Fig. 4) aim at evaluating the quality differences between the 3 links, they actually represent the cumulative PER for each node during the whole hour. From these curves we can observe two important points:

1) Between pelvis and feet:

The difference of cumulative PER between the pelvis link (red curve) and the feet links (green and blue curves) point out the impact of the shadowing due to the important motion of the feet, as their cumulative PER is much higher than for the pelvis link, which is much more stable, and almost always in LOS conditions.

2) Between left and right foot:

Between the left foot (green curve) and the right foot (blue curve), we observe the cumulative PER is multiplied by a factor 2. This is due to the position of the data collector, located ahead but rather on the left of the athlete. Due to this configuration, the right node was subject to shadowing from the runner's own body.

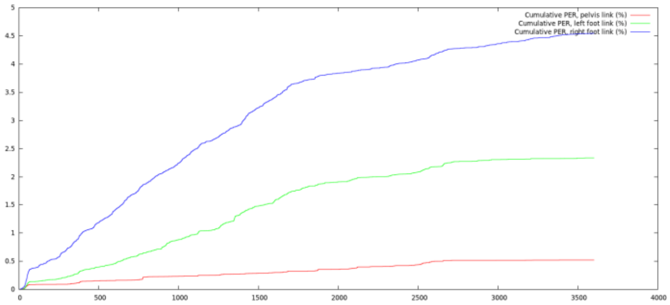

Fig. 4. Cumulative PER (%) vs time(s) for each link (Red: pelvis, Green: left foot, Blue: right foot)

To evaluate the quality of our system, we also computed the average PER and the packet loss distribution for the 3 links (Table 2 & Table 2). Interesting conclusions can be drawn from these results:

- In all cases we have a large majority of only one consecutive packet loss. This means that the period of 40ms associated with frequency hopping is efficient to prevent from fading effects.
- The feet links present an important proportion of five consecutive losses, which can be imputed to the body motion shadowing. This means that a shadowing duration of about 200ms is regularly observed, which may compromise real-time applications.
- The results confirm the quality differences between the three links presented on Fig. 4.

	Total packet loss	Percentage	Max consecutive loss
Pelvis	470	0.52 %	4
Left foot	2100	2.33 %	6
Right foot	4091	4.54 %	9

Table 1. Average PER and maximum consecutive loss for each link

	1	2	3	4	5	6	7	8	9
Pelvis	**92.7 %**	6.3 %	0 %	0.8 %	0 %				
Left foot	**76.9 %**	5.8 %	0.8 %	0.4 %	**14.4 %**	2 %			
Right foot	**67.5 %**	10.4 %	1.2 %	0.4 %	**15.8 %**	3.2 %	1 %	0 %	0.2 %

Table 2. Consecutive packet loss distribution for each link

The association of these two results shows that the effective packet loss (consecutive loss > 3) was actually very low, and that almost no information was lost. These results also point out that other strategies should be used in order to avoid the body shadowing impact.

D. Signal strength & Athlete motion

We were also able to evaluate the impact of the athlete's motion with the Energy Detection (ED) measurement. As the running movement of the athlete was highly periodical, we applied normalized autocorrelation on the left foot ED signal over 20 seconds, during the first half-hour period (Fig. 5). Autocorrelation is a well-known tool that allows the identification of repeating patterns in a 1D signal [17].

As represented on Fig. 5, we observe periodic peaks on the autocorrelation results every 720ms. This duration corresponds exactly to the stride frequency we measured with the accelerometers, pointing out the strong link between the athlete's feet motion and the quality of the signal received.

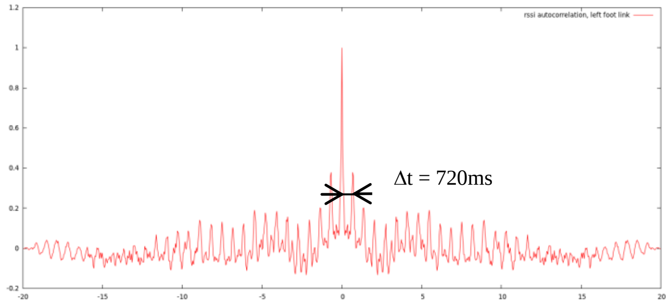

Fig. 5. ED signal autocorrelation, left foot link, 20s duration, high density period (first half-hour)

IV. PERSPECTIVES

The results from section III point out that the data extraction from a BAN in a dense and highly dynamic environment is not an easy thing, especially if we want to be efficient in worse conditions. In this section we discuss the different points to explore in our future works, the problems and steps we need to validate in order to be able to extend our network in an efficient way.

A. *On-Body Data collection and transmission strategies*

As we explained, we developed a very simple platform, which was able to work under rather good conditions and reacted quickly to the loss of contact. The data centralization was done directly on the router, and we showed the important quality disparities between our 3 links, which led to quite an unbalanced network, in terms of packet loss. In our future works, we will need to focus on different methods that could improve the efficiency of our network:

1) Relaying strategies

Usually BAN applications centralize the data on a node located on the body, before transmitting the whole amount of information to an external sink. For our field of application, this network configuration can be critical, for example if the on-body coordinator loses contact with the router while other nodes don't, all the body information can be lost for a while.

In order to reduce the important impact of the body shadowing on the transmissions, nodes can cooperate and act as relays if the data transmission cannot be achieved through the direct path because of a bad channel state [4-7]. This relaying strategy can be performed either in a static or a dynamic way.

In a static way, the knowledge we have on the correlation between the different links is considered sufficient to affect the nodes a systematic relay configuration (e.g. using the right hand to transmit the left foot). This method has the advantage of being easy to implement, but it is highly scenario-dependent.

Dynamic, or opportunistic methods, may be more efficient and flexible, but also more complex. They consist in real time estimations of the links quality, leading to a dynamic selection of the best relay candidate. This method can be coordinated (selection done by the collecting point), or uncoordinated (the node estimates on its own its capacity to relay the data). Periodicity on the links quality could be exploited for this purpose.

2) *Channel & network coding*

In addition to the body shadowing linked to the athlete's motion, the transmission channel is also affected by fast fading, yielding the transmission of erroneous bits, thus erroneous packets. Instead of being considered lost, these packets can be corrected to a certain extent by applying Forward Error Correction (FEC) algorithms, increasing the success probability of the transmission [8-9].

Network coding [10-11] performance can also be evaluated. It consists in combining several packets together between the transmitting nodes instead of relaying the data, increasing the information flow by the addition of diversity.

The combination of these two approaches (relay + coding) [12-13] will help ensuring higher transmission quality at a lower transmission power, which is an important requirement for limiting the interference in the case of an extended network.

B. *Extension of the network to multiple BANs*

The final purpose for this field of BAN application is to design a network architecture that is capable of retrieving the data from a group of athletes, all of them equipped with their own BAN, thus building a real time hierarchical two-level multi-BAN platform. The architecture must also support multiple network sinks. As many athletes in the group will be in NLOS conditions from sinks, a method to estimate the connectivity between them, in order to route the information properly, must be taken into account during the evolution of the group.

We will have to be careful with the latency increase induced by the multi-hop routing technique, and define request/acknowledgement protocols for a sequential data collection.

The validation and the efficiency estimation of our system will be based on these four criteria:

- Latency
- Power consumption & efficiency
- Packet loss
- Network density

C. *Towards a complete system design*

Albeit some results have been already published concerning the BAN channel dynamic [1-2], the results are truly scenario dependent. The results we obtained from this experiment and we will explore deeply in future works, offer a specific insight for a complex dynamic environment.

The design of a complete multi-BAN platform for sports monitoring consists in a combination of typical BAN and networking problems, with particular, scenario-specific conditions and constraints. On the one hand, the network needs to be efficient for on-body data collection, and on the other hand it has to solve dynamic routing problems in a time-constrained way, which limits the data circulation on the network. Body-to-body communication will be as well a challenging constraint for the choice of the routing strategy, which will also have an important influence on the BAN design itself.

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